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Authors' contributions	Conceptualization: Geun-woo Park, Kyu-hyun Park Data curation: Geun-woo Park, Kyu-hyun Park Formal analysis: Geun-woo Park, Kyu-hyun Park Methodology: Geun-woo Park, Kyu-hyun Park Writing - original draft: Geun-woo Park, Mohammad Ataallahi, Kyu-hyun Park Writing - review & editing: Seon Yong Ham, Se Jong Oh, Ki-Youn Kim, Kyu-hyun Park
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Original article

Estimating losses in milk production by heat stress and environmental impacts of greenhouse gas emissions in Korean dairy farms

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Abstract

Meteorological disasters caused by climate change like heat, cold waves, and unusually long rainy seasons affect the milk productivity of cows. Studies have been conducted on how milk productivity and milk compositions change due to heat stress (HS). However, the estimation of losses in milk production due to HS and hereby environmental impacts of greenhouse gas (GHG) emissions are yet to be evaluated in Korean dairy farms. Dairy milk production and milk compositions data from March to October 2018, provided by the Korea Dairy Committee (KDC), were used to compare regional milk production with the temperature-humidity index (THI). Raw data for the daily temperature and relative humidity in 2018 were obtained from the Korea Meteorological Administration (KMA). This data was used to calculate the THI and the difference between the maximum and minimum temperature changing rate, as the average daily temperature range, to show the extent to which the temperature gap can affect milk productivity. The amount of milk was calculated based on the price of 926 won/kg from KDC. The results showed that the average milk production rate was the highest within the THI range 60-73 in three regions in May: Chulwon (northern region), Hwasung (central region), and Gunwi (southern region). The average milk production decreased by 4.96±1.48% in northern region, 7.12±2.36% in central region, and 7.94±2.57% in southern region from June to August, which had a THI range of 73 or more, when compared to May. Based on the results, the level of THI should be maintained like May. If so, the farmers can earn a profit of 9,128,730 won/farm in northern region, 9,967,880 won/farm in central region, and 12,245,300 won/farm in southern region. Additionally, the average number of cows raised can be reduced by 2.41±0.35 heads/farm, thereby reducing GHG emissions by 29.61±4.36 kg CO_2eq/day on average. Overall, the conclusion suggests that maintaining environmental conditions in the summer that are similar to those in May is necessary. This knowledge can be used for basic research to persuade farmers to change farm facilities to increase the economic benefits and improve animal welfare.

Keywords: Climate change, Dairy milk productions, Economic assessment, Environmental assessment, Temperature-humidity index, Heat stress

Background

In South Korea, climate change has affected weather conditions, increasing the frequency of heat waves (HW) and average daily temperatures [1]. The mean annual average temperature increased by 0.5℃ from 2010 to 2019, which is higher than the climatological standard from 1981 to 2010 [2]. Increased temperatures due to climate change may impact animal health and performance. All animals have their own range of ambient environmental temperatures, termed the thermo-neutral zone, to maintain core body temperature [3]. The thermo-neutral zone for dairy cows varies widely from approximately -5℃ to 25℃. This range of temperature is more conducive to promoting good health and performance in cows [4]. The upper critical temperature is the point at which heat stress (HS) begins to affect the animal. The HS can be simply defined as the point at which the cow cannot dissipate an adequate quantity of heat to maintain thermal balance [5,6].

There are several environmental factors, including high temperature, high humidity, and radiant energy (sunlight), which contribute change to induce HS. The environmental conditions that induce HS can be calculated using the temperature-humidity index (THI), which is a combination of temperature and humidity data [7]. Among the various available methods, such as heat load index, black globe humidity index, equivalent temperature index, and environmental stress index, the THI is a suitable and simple indicator for monitoring the impacts of microclimate factors on dairy cows. HS can affect animal production and profitability in dairy cattle by lowering feed intake, milk production, and reproduction [8]. There are several management and housing alterations that can be made to decrease the impact of HS. The challenge with these is balancing the investment cost with the projected production and economic responses [9].

In aspects of greenhouse gas emissions (GHG) as the assessment of environmental impact, under HS, as Vitali [10] mentioned that the methane emission intensity was found as 0.400 and 0.388 kg CO_2eq /kg FPCM for HS and thermos-neutral scenario, respectively. It increased 12 grams CO_2eq/kg FPCM (kg fat and protein corrected milk) or 60 tons-CO_2eq and it seemed that the effect of HS may affect the increase of GHG [10]. The assessment of GHG emissions is recommended as options for climate change mitigation and it is a key element of sustainable milk production [11]. This study aimed to analyze the average monthly THI changes in relation to milk production and milk compositions. We also sought to gather basic data by investigating changes in livestock productivity and validating the impact and vulnerability data due to climate change, as specified in the framework act on agricultural food from the Ministry of Agriculture Food and Rural Affairs (MAFRA). This research suggests to what extent farmers can increase milk productivity, increase profits, and reduce GHG, when they manage their farm's thermal environment.

MATERIALS AND METHODS

This research was conducted in three regions in South Korea: Chulwon (38.1466°, 127.3132°) located in the north , Hwasung (37.570705°, 126.981354°) located in the center, and Gunwi (36.2428°, 128.5728°) located in the south. We sought to analyze the effect of HS on milk production and the quality of milk compositions. The number of farm households in northern region was 105±0.64, in southern region, it was 9±0, and in central region, it was 298±2.38;

these numbers changed each month. All of these regions showed the highest milk yields, maximum temperatures, and THI_{max} values (THI with maximum temperature), which could lead to prudent results.

Microclimate data

In this study, microclimate data, including temperature and relative humidity, were collected from the Korea Meteorological Administration (KMA) (http://www.kma.go.kr). The sum of the number of days with HW per year in the South Korea, from 2010 to 2019, was calculated to choose which year had the most losses in milk production and quality [12].

Daily weather records from three KMA stations in 2018 were used to estimate the monthly mean maximum temperature and monthly average humidity data, as well as the difference between the maximum and minimum temperatures, to show the changing rate of the temperature gap as the average daily temperature difference. The maximum temperature clearly reflects the THI results that affect milk quality and production [13]. The summer period was set from June to August because the average monthly temperature, daily average temperature, maximum temperature, and minimum temperature in the three regions steadily increased.

Temperature-humidity index (THI)

The THI equation was used from March to October in 2018 to estimate changes in milk production and quality due to HS [14].

$$THI = (0.8 \times Tdb^{*}) + [(RH^{**} \div 100) \times (Tdb - 14.4)] + 46.4$$

Tdb*: Dry bulb temperature (℃)

RH** : Relative humidity (%)

When the THI is >72, HS begins to occur in dairy cattle. As the THI increased, there were some signs of HS exhibited by the cows; these are shown in Table 1 [1,15,16].

Milk production, economic evaluation, and milk compositions

To compare regional milk production with the THI unit, we used milk production and milk compositions data, such as milk protein (MP), milk fat (MF), somatic cell counts (SCC), and total bacterial counts (TBC), from March to October 2018. These data were provided by the Korea Dairy Committee (KDC). Instead of using the traditional units for MP and MF percentage, total MP per farm and total MF per farm (g/farm) was used, reflecting the fact that MF and MP can be diluted when the amount of milk production increases. For this reason, these units were converted to g/farm/day by multiplying the yield of milk (L) per farm and dividing it by the number of days in each month. The SCC unit (SCC/mL) and TBC unit (cfu/mL) were also converted to SCC/farm/day and cfu/farm/day, respectively, for the same reason [17]. In 2018, the average milk production rate in certified dairy cow farms was 10,303 kg/head/year and 9,408 kg/head/year in South Korea, as announced by MAFRA and Korea Statistics (KOSIS) [18,19]. Furthermore, economic evaluation by milk production was calculated as 926 won/kg. This evaluation included the price of milk compositions such as MF and MP, and hygiene parameters such as SCC and TBC levels, which were announced by the KDC in 2018 [20].

Greenhouse gas emissions data

The GHG inventory data of the agricultural sector in 2017, which included enteric fermentation and manure management data from dairy cattle, were used to calculate the amount of GHG emissions per head of cattle. The data were obtained from the National Greenhouse Gas Inventory Report of Korea, 2019 [21,22]. The total number of heads of dairy cattle was approximately 412,000, while the total gas emitted from enteric fermentation was 1,022,000 tCO_2eq and the total gas emitted from manure management emitted was 523,000 tCO_2eq in 2017. Based on that data, 12.30 kg CO_2eq/head/day can be calculated.

RESULTS AND DISCUSSIONS

The microclimate data, such as maximum temperature and average humidity, were selected based on the highest number of days with HW: 49 days in southern region, 38 days in central region, and 24 days in northern region respectively in 2018, as presented in Fig 1. The summer period set as June to August, the average maximum temperature in northern region was 30.02±2.03℃; in southern region it was 32.88±2.60℃ and in central region it was 31.57±2.57℃. In northern region, climatic conditions were cooler than those of central and southern region during the summer period.

The high temperature can increase the cortisol levels and affect the milk production from cows [23]. At the same time, it can increase the milk antioxidant levels which can decrease the milk quality in summer seasons from June to August [24]. Bohmanova et al. [25] reported that seasonal differences in milk production are caused by periodic changes of environment over the year, which has a direct effect on animal's milk production through decreased dry mass intake and an indirect effect through fluctuation in quantity and quality of feed. In Fig. 2, we analyzed the data for the total milk production per farm from March to October 2018, depending on the THI, as well as the difference between the maximum THI (THI_{max}) and the minimum THI (THI_{min}). In northern region (Fig.2 (A)), milk production per farm increased as the THI level increased, from approximately 70 to 75 until May. However, when compared to May, milk production per farm decreased by 6.13% in June, 3.29% in July, and approximately 5.47% in August. In other words, from June to August, milk production per farm decreased by 4.96±1.49%. Subsequently, from September to October, after the THI level decreased, milk production per farm started increasing by 1.40±1.13%. In central region (Fig.2 (B)), milk production per farm increased as the THI level increased, from approximately 70 to 75 until May, the same as in northern region. Nevertheless, compared to May, milk production per farm decreased by 5.94% in June, 5.59% in July, and approximately 9.84% in August. In other words, from June to August, milk production per farm decreased by 7.12±2.36%. Thereafter, from September to October, milk production per farm started increasing by 1.19±2.16%, after the THI level decreased. In southern region (Fig. 2 (C)), milk production per farm increased as the THI level increased, from approximately 70 to 75 until May. However, compared to May, milk production per farm decreased by 5.13% in June, 8.53% in July, and approximately 10.16% in August. In other words, from June to August, milk production per farm decreased by 7.94±2.57%. Unlike northern and central region, from September to October, milk production per farm decreased by 1.85±1.93%, after the THI level decreased. The THI level approached over 80 and had a negative impact on milk production per farm. As a result, milk production in all regions decreased when THI was exceeded 75, and increased again when THI was below 75. Our study results are supported by Bohmanova et al. [25] who reported that even with use of evaporative cooling, THI can't drop below 72, this may explain the sharp decline of milk production from June to August. Dong-Hyun Lim et al. [26] reported that the greater heat production can explain the increasing rate of decline in milk yield for cows. Also, Bohmanova et al. [25] showed milk production begins to recover from HS in October when THI was <72. However, if the impacts of HS conditions were prolonged, reduced milk yield was seen well after the heat load period has abated. Then, milk production may not return to pre-exposure production levels [27]. In addition, the difference between THI_{max} and THI_{min} decreased during summer in Fig. 2. As the small differences between THI_{max} and THI_{min} are affected to cows' rectal temperature that have to be cool down at night, it can be related to loss of milk productions. The small gap between THI_{max} and THI_{min} meant that the heat at noon in summer was not easily cooled at night [28]. This causes HS in dairy cows because lactating dairy cows produce a great quantity of metabolic heat and accumulate additional heat from radiant energy, which is linked to a reduction in milk production per farm [25]. Staples et al. [29] found the important consideration is that the heat load is considered to have a greater impact on high production cows.

For milk compositions, there are four factors to evaluate: total milk protein (TMP) per farm (g/farm), total milk fat (TMF) per farm (g/fram), daily somatic cell count per farm (SCC/farm/day), and daily TBC per farm (cfu/farm/day), as shown in Fig. 3. To exclude the dilution of milk, fat and protein contents were calculated by multiplying the total amount of milk. Similarly, for SCC and TBC, to exclude dilution, SCC and TBC were divided into farms per day. In northern region (Fig. 3 (A)-1), the TMP and TMF decreased by 7.04±1.82% and 7.03±1.31%, respectively, when May was compared with the average value from the June to August. In central region (Fig. 3 (A)-2), the TMP and TMF decreased by 7.12±2.36% and 8.96±3.27%, respectively, when May was compared with the average value from the June to August. Similarly, in southern region (Fig. 3 (A)-3), the TMP and TMF decreased by 9.13±1.90% and 12.44±5.45%, respectively, when May was compared with the average value from the June to August. It is suggested that the TMF and TMP were decreased when THI was over 75. Bernabucci et al. [30] supported our results that HS induced the reduction of total milk protein and also lower the casein contents in cattle. Pragna et al. [31] also mentioned that HS reduced MP, MF solids-not-fat (SNF) in dairy cows. Further, HS reduced MF, MP and short-chain fatty acids while increased the long chain fatty acids in the milk [32]. Also, the reason of decrease on milk compositions as MP and MF would be the decrease of feed intake, and increase of drinking water which can occur the dilution of milk compositions [25]. Gerner et al. [33] found that cows exposed to heat produced milk with a lactose and protein composition 49% lower than thermo-neutral control cows.

The SCC decreased from March to May but started increasing again from June to August, but it did not contribute to a decrease in milk prices in all regions (Fig. 3 (B)-1, Fig. 3 (B)-2, Fig. 3 (B)-3). However, TBC fluctuated from March to October in all regions (Fig. 3 (B)-1, Fig. 3 (B)-2, Fig. 3 (B)-3). In particular, in March, TBC was higher than in any other month. This may be because the winter season in the South Korea is cold enough to crystalize the cows' bedding and litter, thus this may have wounded the nipples of the cows, increasing the number of germs [34]. Mohebbi-Fani et al. [35] mentioned that MP and MF are the two major milk compositions affecting milk price. Likewise, these results showed that a reduction in TMF and TMP affected milk price, but not SCC and TBC. The milk price per liter against the THI shown in Fig. 4. The basic price of milk per liter was 926 won/L, and four factors increased the milk price including MP, MF, SCC, and TBC [36]. This showed that in the summer season from June to August, milk price per liter decreased, thus decreasing farmers' profits. Traditionally, a THI value of 72 has been used as a threshold to predict whether or not dairy cattle experienced HS. When the THI level is maintained below 72, as it is in May, each farm can earn additional revenue from June through August, as shown in Table 2. At first, in northern region (Fig. 4 (A)), when the THI level was maintained below 72, the additional milk production reached 2,546.12 kg/farm in June, 1,366.72 kg/farm in July, and 2,639.35 kg/farm in August, for a total of 6,552.20 kg/farm. As shown in Fig. 4, when additional milk production was multiplied by the milk price from June to August, which is 1,050 won/L, the additional revenue was 9,128,730 won/farm. Likewise, in central region (Fig. 4 (B)), when the THI level was below 72, the additional milk production was 2,220.17 kg/farm in June, 1,732.02 kg/farm in July, and 3,454.51 kg/farm in August, for a total of 7,406.70 kg/farm. As shown in Fig. 4, as the additional milk production was multiplied by the milk price from June to August, which is 1,060 won/L in June and July, and 1,032 won/L in August, the additional revenue was 9,967,880 won/farm. Finally, in southern region, when the THI level was below 72, the additional milk production was 1,732.11 kg/farm in June, 2,882.33 kg/farm in July, and 3,432.89 kg/farm in August, for a total of 8,047.33 kg/farm. As shown in Figure 4, when the additional milk production was multiplied by the milk price from June to August, which is 1,066 won/L in June, 1,042 won/L in July, and 1,029 won/L in August, the additional revenue was 12,245,300 won/farm. Therefore, further studies are required on the methods of controlling the THI level below 75 in order to increase the quality of milk compositions including MF, MP, SCC and TBC. Given this, increasing milk quality and quantity can result in additional income enabling farmers to improve the systems or facilities to decrease HS in dairy cattle [37]. Previous researches have documented the effect of HS on milk quality in dairy cattle [23,25,38]. However, those didn't apply the milk compositions for calculating the milk price in each monthly or annually to evaluate how much revenue can be earned. This study showed the results of total additional earning by applying the factors of milk compositions per price. In order to calculate the exact additional revenue during the hot weather condition, farmers and companies which is related to milk industry have to manage and collect the precise and accurate data from the farm [39].

Regarding the environmental aspects, Table 3 shows the expected decrease in the heads of dairy cattle and GHG emission amount when the THI level remains below 72 in the summer season from June to August. When the THI was below 72, the additional milk production was 6,211.63 kg/farm in northern region. This meant that the daily milk production rate on farms was 67.52 kg/farm/day. According to the KDC, in 2018 in the South Korea, yearly milk production was 9,408 kg/head, which equates to 30.85 kg/head/day [19]. Based on that data, the farm in northern region can reduce 2.00 head/farm and decrease GHG emission by 24.58 kg CO_2eq/day. In central and southern region, when the THI level was kept below 72 the additional milk production went up to 8,027.35 kg/farm and 8,199.16 kg/farm, respectively, from June to August. This meant that if the daily milk production rate in the farms was 87.25 kg/farm/day and 89.12 kg/farm/day, then the farms in central and southern region can reduce 2.58 head/farm and 2.64 head/farm, while decreasing GHG emissions by 31.77 kg CO_2eq/day and 32.45 kg CO_2eq/day, respectively. Keeping the THI level below 72 can reduce livestock head by 2.41±0.35 per farm and reduce GHG emissions by 29.61±4.36 kg CO_2eq/day on average. In addition, the cows' feed intake can be increased to prevent the risk of diseases, such as metabolic and digestive malfunctions in low THI condition [40]. There are limitations to use the data for the GHG emissions related to milk production and also it is difficult to obtain the data of milk production per head because of the privacy policy agreement. It is suggested that dairy farmers and milk companies try to open the milk production per lactating head data for the additional research to improve the dairy industry by avoiding the issues on privacy problems. Furthermore, the systematic managing program for dairy cattle would be needed as checking the conditions and numbers of cattle, energy usage in farm, and surrounded environmental factors to conduct the further research for the GHG emission and economical assessment.

CONCLUSION

This study demonstrated that seasons with high-temperature can affect milk production and milk compositions. In particular, milk price per liter and milk production were affected in the southern region of South Korea, which did not easily cool down at night. It is believed that farms will have to make efforts to achieve long-term profits by managing the high-temperature specifications for cows and invest in facilities to maintain the THI below 72. Further studies are needed to consider cold stress in the winter season to complement year-round management. In addition, selecting more cities in subsequent studies can produce more statistically significant results. Moreover, the exact number of lactating dairy cattle can help better predict the exact profits and the extent to which GHG emissions can be reduced. Moreover, a decrease in the number of dairy cattle can reduce the cost of feed, and waste products and manure excreted by livestock. This may be connected to the mitigation of climate change, as decreasing manure quantities can reduce GHG emissions. Finally, analyzing the stress hormones is necessary to quantify the stress of cows during hot and cold seasons or when seasons change. This can be matched with the seasonal effect to verify the heat and cold stresses considerably. This study suggests that high temperatures can negatively affect milk productivity and milk compositions. To improve the farmer's income and working environment, regional and seasonal heat or cold stress manuals should be customized, and further research is needed to use the precision dairy monitoring technologies and validate that systems or facilities such as cooling ventilation or shade can increase the dairy productivity and lessen the cow's stress.

Abbreviations

HS : Heat stress

THI : Temperature-humidity index

GHG : Greenhouse gas

MAFRA : Ministry of Agriculture, Food and Rural Affairs

KOSIS : Korea Statistics

KDC : Korea Dairy Committee

KMA : Korea Meteorological Administration

MP : Milk protein

MF : Milk fat

TMP: Total milk protein

TMF: Total milk fat

SCC : Somatic Cell Count

TBC : Total Bacterial Count

HW : Heat wave

Declarations

Nothing to declare.

Ethics approval and consent to participate

This article does not contain any studies with human subjects performed by any of the authors. The experimental procedure and methods were approved by the Animal Welfare and Ethics Authority of Kangwon National University, Chuncheon, Republic of Korea.

Consent for publication

Not applicable.

Availability of data and materials

Please contact author for data requests.

Competing interests

The authors declare no conflict of interest.

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Table 1. Effect of heat stress on dairy cattle according to the temperature-humidity index (THI)

THI	Stress level	Comments
<72	None	-
72 – 79	Mild – moderate stress	Dairy cows will adjust by seeking shade, increasing respiration rate, and dilating blood vessels. The effect on milk production will be minimal.
80 – 89	Moderate – severe stress	Both saliva production and respiration rate will increase. Feed intake may be depressed and water consumption will increase. There will be an increase in body temperature. Milk production and reproduction will be decreased.
90 – 98	Severe stress	Cows will become very uncomfortable due to high body temperature, rapid respiration (panting), and excessive saliva production. Milk production and reproduction will be markedly decreased.
>98	Danger	Potential cow deaths can occur.

Table 2. Values of increasing milk production and profit obtained from maintaining a THI level below 72

Cities / Categories	Northern region	Central region	Southern region
Increasing milk amount per farm (kg/farm)	6,552.20	7,406.70	8,047.33
Economic profits (won/farm)	9,128,730	9,967,880	12,245,310

* The price of milk was cut below 1 won.

Table 3. The possibility of decreasing the heads of cattle and GHG emissions by maintaining the THI level below 72

Cities / Categories	Northern region	Central region	Southern region
The number of cows (head/farm)	2.00	2.58	2.64
GHG emissions (kg CO_2eq/day)	27.54	31.77	32.45

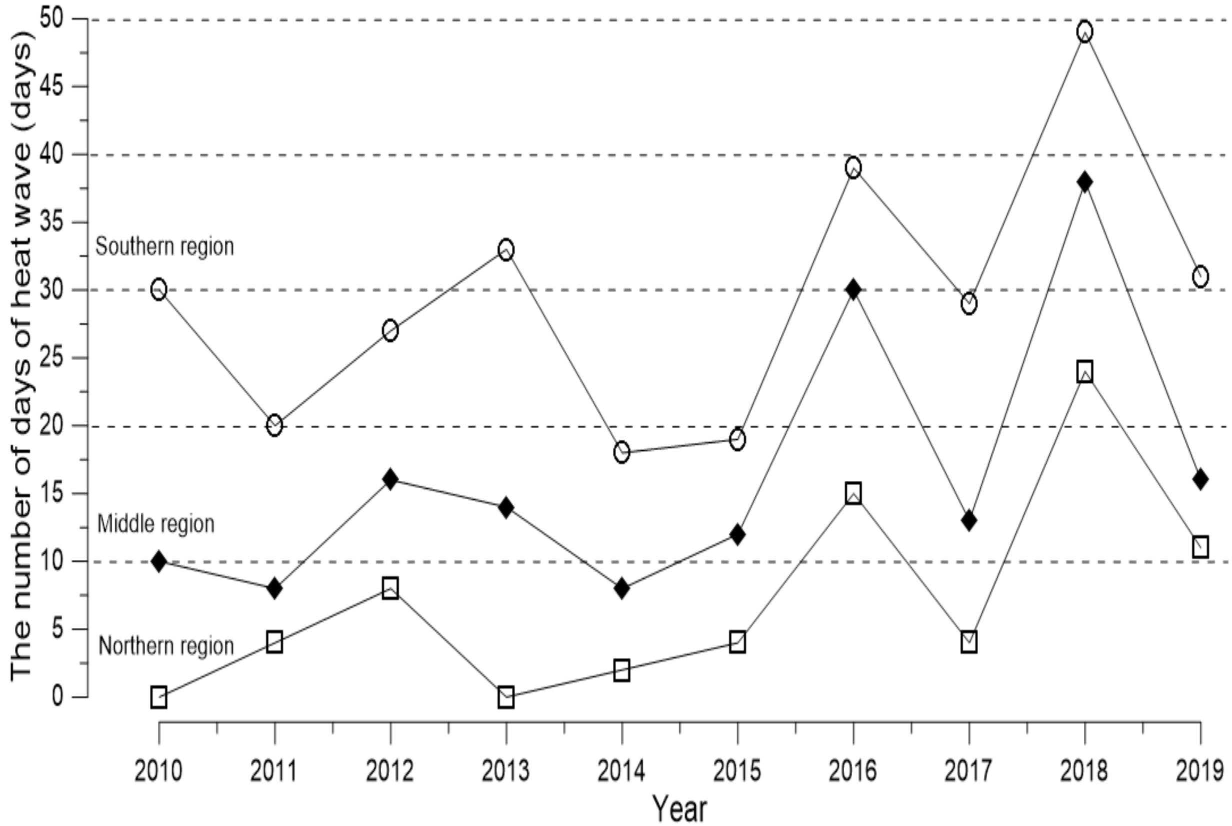

Fig. 1. The annual number of days of HW in the three regions. The blank circle (○) shape represents southern region, filled rhombus shape (◆) represents central region, and blank square (□) shape represents northern region. All regions have the highest number of days of HW in 2018.

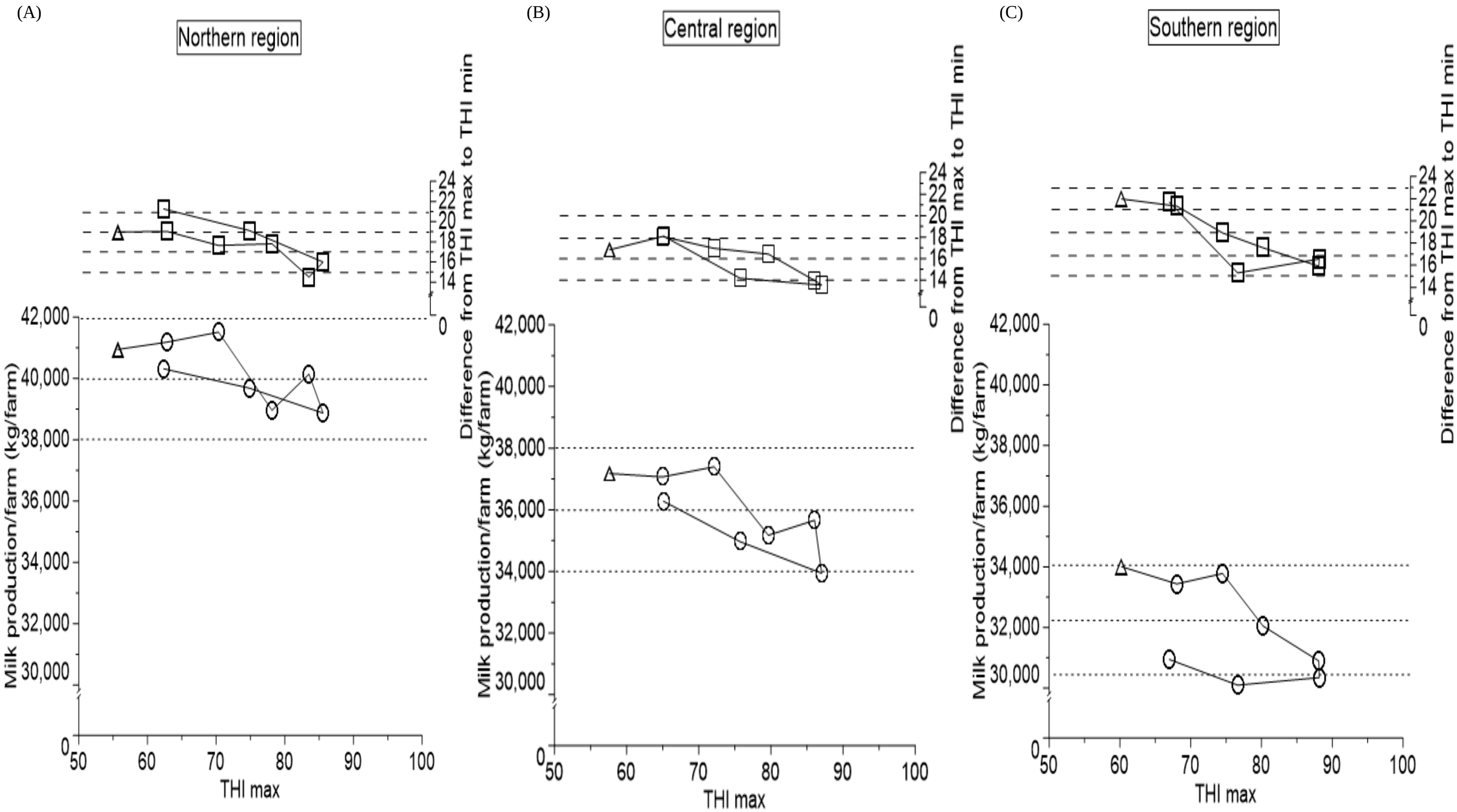

Fig. 2. The average milk production level for the farms (kg/farm) in each of the three regions (A) northern region, (B) central region, and (C) southern region against the maximum temperature-humidity index (THI_{max}). The graph of milk production per farm started from March (△) and followed the line from

April to October (○). The upper graph presents the difference between the THI_{max} and THI_{min}, which is calculated by maximum temperature and minimum temperature. It started from March (△) and followed the line from April to October (□).

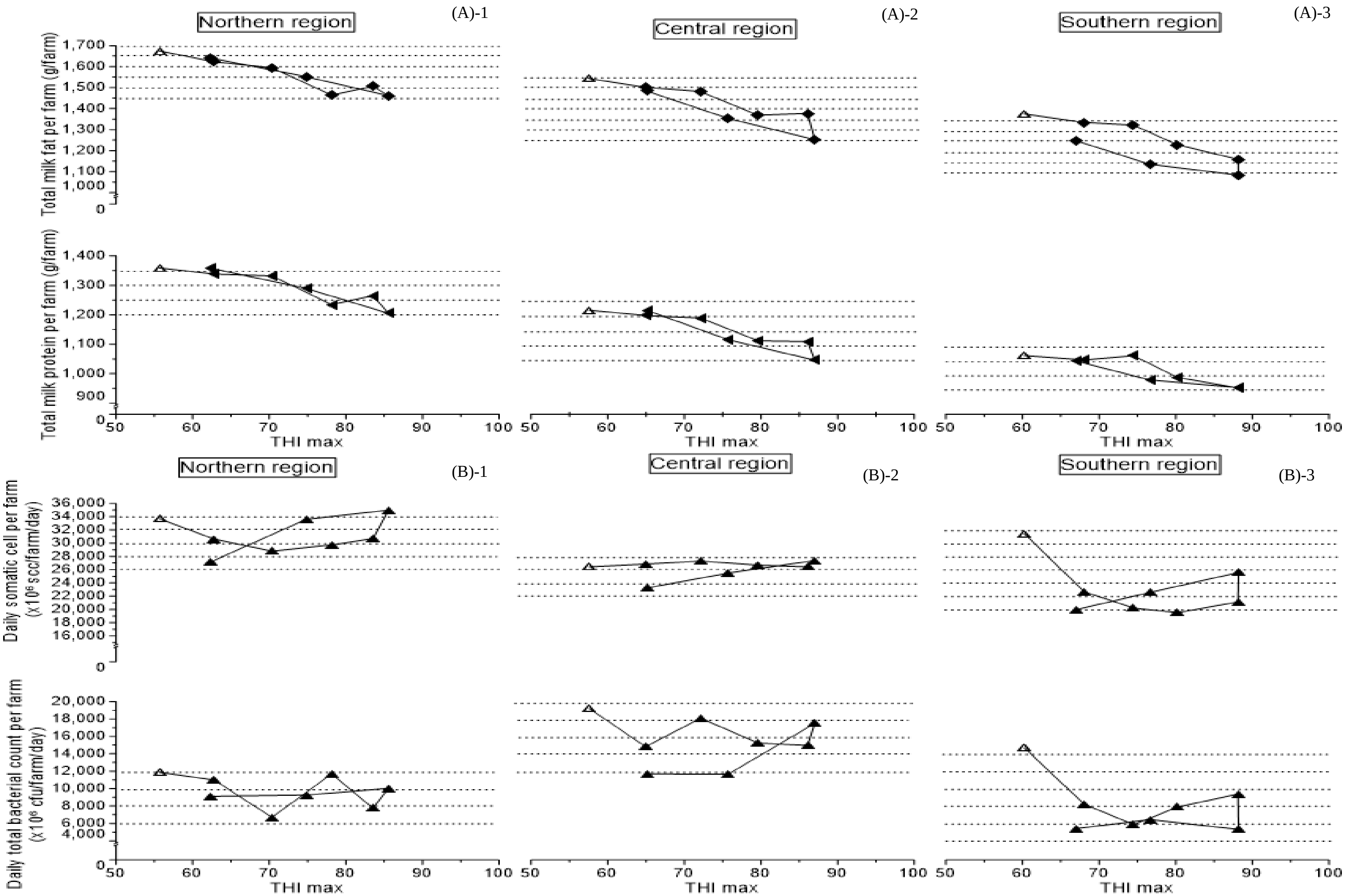

Fig. 3. The TMP per farm (g/farm), TMF per farm(g), daily somatic cell count per farm (scc/farm/day), and daily TBC per farm (cfu/farm/day) for each region: northern region, central region, and southern region against the maximum temperature-humidity index (THI$_{max}$). The (A)-1, (A)-2, and (A)-3 graph

of TMF and TMP, which is for northern region, central region, and southern region, respectively, started from March (△) and followed the line from April to October(◆) and (◀), respectively. The (B)-1, (B)-2, (B)-3 graph is for total somatic cell count and total bacterial counts for each region. It started from March (△) and followed the line from April to October (▲). The number inside parentheses is each month's THI value.

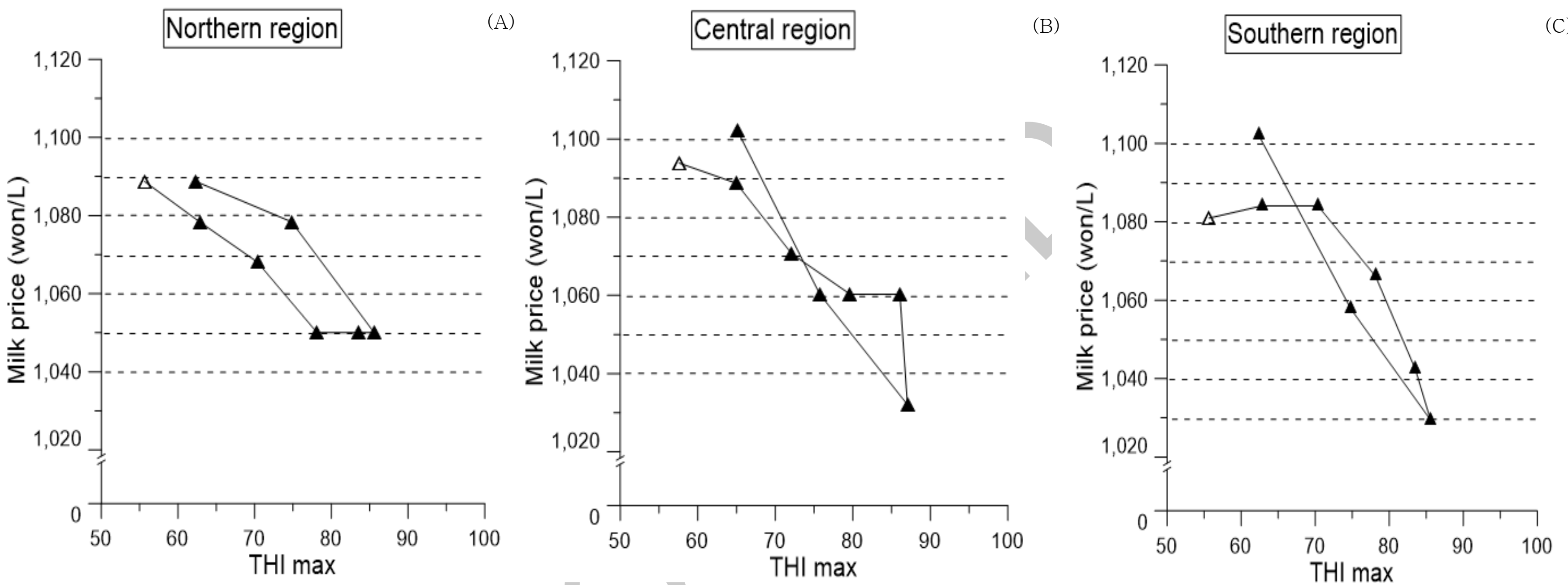

Fig. 4. The milk price for each region (won/L) for (A) northern region, (B) central region, and (C) southern region against the maximum temperature-humidity index (THI_{max}). The graph of milk price started from March (△) and followed the line from April to October (▲).